NARRAGANSETT MARINE LABORATORY

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ACOUSTICS PROJECT

Seismic Refraction Investigations in Selected Areas of Narragansett Bay, Rhode Island

by

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PREFACE

The seismic refraction results contained in this report complete the third phase of an investigation begun in 1955 for the purpose of making available sound transmission data, bottom sediment data, and geological structure data for certain areas of Narragansett Bay.

Sound transmission information has been reported in the following reports:

<u>Shallow Water Explosive Sound Transmission Runs in Narragansett Bay</u>, by F. T. Dietz, W. B. Birch, and C. V. Mulholland, N.M.L. Reference No. 57-3, 1957.

<u>Shallow Water Explosive Sound Transmission Runs in Narragansett Bay (Addendum)</u>, by F. T. Dietz, W. B. Birch, and C. V. Mulholland, N.M.L. Reference No. 58-3, 1958.

<u>Shallow Water Continuous Wave Sound Transmission Runs</u>, by F. T. Dietz, W. B. Birch, and C. V. Mulholland, N.M.L. Reference No. 58-5, 1958.

<u>Shallow Water Continuous Wave Sound Transmission Runs (Addendum)</u>, F. T. Dietz, W. B. Birch, and C. V. Mulholland, N.M.L. Reference No. 58-6, 1958.

Information on the local sediment types was given in:

<u>Analysis of Cores from Ranges Able, Baker, Charlie, and Dog, Narragansett Bay - 1955</u>, by C. V. Mulholland and F. T. Dietz, N.M.L. Reference No. 56-8, 1956.

<u>A Direct Measurement of Sound Velocities in Narragansett Bay Sediments</u>, by F. T. Dietz, C. V. Mulholland, and W. B. Birch, N.M.L. Reference No. 58-4, 1958.

The geographical areas investigated in this report are designated as Profiles 1 through 14. In the earlier reports mentioned above, these same areas have been called ranges Able, Baker, Charlie, and Dog. For clarification the following list is given:

<u>Present Report</u>		<u>Previous Reports</u>
Profiles 1, 2, 3, 4	correspond to	Range Able
Profiles 5, 6, 7, 8	correspond to	Range Charlie
Profiles 9, 10	correspond to	Range Dog
Profiles 11, 12, 13, 14	correspond to	Range Baker

ABSTRACT

Seven reversed refraction profiles have been fired in four shallow water areas in Narragansett Bay, Rhode Island. The results are presented in the form of reversed travel time graphs and cross sectional representations of the strata. Seismic velocities and layer depths are shown in tabular form.

Three ranges of velocities were obtained:

(1) Sediment velocities varying from 1.54 km/sec to 1.77 km/sec;

(2) Intermediate velocities of from 4.16 km/sec to 5.11 km/sec, associated with the Rhode Island formation;

(3) High speed velocities ranging from 5.54 km/sec to 6.46 km/sec, associated with a granite or crystalline third layer.

In the areas under investigation, the thickness of the sediment layer varies from about 14 meters to 52 meters, with the thicker portions generally occurring in the northernmost area. The depth of the upper refracting horizon, the boundary between the sediment layer and the intermediate layer, varies from 23 meters to 45 meters below mean low water. The intermediate layer varies in thickness from approximately 290 meters at the northern end of the bay to 58 meters toward the south. The lower refracting horizon, the boundary between the intermediate layer and the third layer, ranges in depth from 85 meters to 340 meters below the datum level.

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I. INTRODUCTION

The work described in this report was performed under Contract Nonr-396(04) between the Office of Naval Research and the Narragansett Marine Laboratory of the University of Rhode Island.

This report is based on part of a thesis presented by the first author to the University of Rhode Island in June, 1961, in partial fulfillment of the requirements for the Degree of Master of Science in Physics.

During the summer of 1955, seismic refraction data were obtained for four shallow water areas in the West Passage of Narragansett Bay, Rhode Island, as part of an explosive sound transmission investigation. In 1956, supplementary seismic measurements were made in the same areas to determine sediment depths and velocities, and to provide additional information concerning intermediate layer velocities. In this paper, the results are summarized and presented in the form of reversed travel time graphs and cross sectional representations of the strata.

Narragansett Bay lies in the southeastern part of the state of Rhode Island and is a part of the Narragansett Basin, a product of continental downwarping and subsequent deposition, which extends north and south in Rhode Island and northeastward into Massachusetts (Shaler et al., 1899). The bay is bounded, and largely underlain, by the Rhode Island formation, a thick series of conglomerate, sandstone, schist, phyllite, and meta-anthracite (Quinn, 1952). The Rhode Island formation is encircled by plutonic rock, chiefly granitic (Quinn and Oliver, in press). In some locations the granitic rock is separated from the Rhode Island formation by the Pondville conglomerate, a thin strip of arkosic rock and quartzitic conglomerates (Quinn, 1952) and (Nichols, 1956). However, the Pondville formation does not extend into the areas under investigation in this paper. The sedimentary beds of the basin were intensely folded during the Appalachian Revolution, resulting in the formation of complicated folds whose axes trend generally north in the Bay area and northeast into Massachusetts.

The bottom sediments of the upper regions of the bay consist mainly of sand, silt, and clay and combinations thereof (McMaster, 1960). Toward the mouth of the bay there is a tendency for the sediments to become coarser. Borings made by Fink (Woods Hole Oceanographic Institution, private communication, 1957) in the vicinity of the Quonset Naval Air Station channel reached depths of from 13.7 to 38.7 meters below mean low water, and indications are that the sediment varies from fine sand and silty clay at the surface to medium sand and fine gravel at depth.

The locations of the seven reversed profiles are shown in Fig. 1 and Fig. 2. Three of the areas were situated in the West Passage of the bay in the Wickford region. The fourth area was located at the north end of the West Passage in Greenwich Bay. These areas were chosen since they had been the sites of previous investigations (Nixon, 1954) and since the composition of the surface sediments had been determined by coring operations (Mulholland and Dietz, 1956).

All references to depths in this paper are with respect to mean low water.

II. 1955 OPERATIONS

Field Methods:

The 1955 data were obtained from four reversed profiles, varying from 2.3 km to 3.2 km in length. Two vessels were used, a listening ship, the R/V Virginia, and a shooting ship, a converted LCVP. The explosive charges consisted mainly of one-half pound TNT-Tetryl demolition blocks, detonated by U.S.A. special non-electric blasting caps. Occasionally, two and one-half pound charges of the same explosive were used. All charges were detonated on the bottom.

Instrumentation:

A single Brush AX-58C hydrophone equipped with a WHOI (Woods Hole Oceanographic Institution) type pre-amplifier was used as a receiver. The hydrophone was bottomed as far as possible from the listening ship in order to eliminate any influence of the ship on the sound field. Its position was marked by a buoy to assist the LCVP skipper in steering his course. The hydrophone was connected to a WHOI two channel amplifier (Dow, 1952). High and low pass electronic filters provided water wave and ground wave information, which was fed into two channels of a four channel driver amplifier (Dow, 1952) and then into a Sanborn Model 154-100 four channel direct writing recorder. A broad band signal was recorded on a third channel of the Sanborn recorder. The fourth channel of the Sanborn recorded one second time ticks from a break circuit chronometer and also the radio transmitted shot instant from the shooting ship. The Sanborn was operated at its maximum paper speed of 100 mm/sec. A block diagram of the instrumentation is shown in Fig. 3.

The shooting ship was equipped with a Brush Type BL-222 two channel recorder and an Atlantic Research Corporation Type BC-50 hydrophone. These were used to record the elapsed time between the shot over-the-side time and the detonation time. Time ticks were provided by a break circuit chronometer. This information, coupled with a knowledge of the speed of the shooting ship, provided the information necessary to correct the shot instant for the separation between the radio transmitter and the exploding charge.

III. 1956 OPERATIONS

Field Methods:

The 1956 methods were designed to give more precise information regarding the sediment layer than were obtained from the 1955 data. Since most of the shots fired in 1955 were too far from the receiver to permit identification of any sediment arrivals, a series of charges were fired at closer ranges than in the previous experiment. It was also felt that since the horizons beneath the bay are known to be complicated, a short profile would be less subject to variations in the strata than would a long profile.

Only one vessel, the R/V Virginia, and three skiffs, designated here as A, B, and C, were required for the 1956 work. A "shot cable" was used, consisting of a 213.4 meter length of stainless steel cable to which snap rings were attached every 7.6 meters. Taped to this cable was a length of two conductor rubber covered electrical cable to which a leader was spliced at every other snap ring. In practice, an explosive charge was connected to each leader in turn, resulting in shots spaced at 15.2 meter intervals along the cable. A metal ball float was attached to each snap ring by means of a short length of line and a snap hook, so that the entire cable floated about 0.3 meters beneath the water surface.

In operation, the listening ship would be securely anchored at one end of a range and skiff A would be anchored nearby. The ring at one end of the shot cable would be fastened to the skiff and the entire cable stretched out by means of a second skiff B equipped with an outboard motor. The third skiff C would be fastened to the ring at the other end of the cable and the entire assembly pulled taut. Skiff C would then be anchored. Any slack in the cable would be removed by taking up on the anchor line of skiff A. The cable arrangement is shown in Fig. 4.

The charges used were one-half pound TNT-Tetryl demolition blocks detonated by DuPont No. 6 electric blasting caps fired from the listening ship. A charge would be attached to one of the leaders from the shot cable, the leader being long enough to allow the charge to lie on the bottom beneath the snap ring and ball float. Weights were attached to the charge to offset any displacement of the charge by tidal currents. The charges would be attached by personnel using skiff B, which would then retire to a safe distance while the shot was being fired. In this manner the shots were spaced at each of 13 controlled distances from the receiving hydrophone which was bottomed directly beneath the ring attached to skiff A.

When a series of shots was completed, the listening ship would retrieve the hydrophone and proceed to the other end of the range and anchor. The hydrophone would be bottomed beneath the snap ring attached to skiff C, and the entire shooting procedure repeated.

Instrumentation:

A Brush AX-58C hydrophone and a two channel WHOI amplifier were used. The broad band output from one channel of the amplifier was split and fed into two channels of a Hathaway oscillograph camera, one channel being operated at a higher gain than the other. The output from the second channel of the WHOI amplifier was high pass filtered, rectified, and fed into a third channel of the oscillograph camera. A crystal controlled oscillator provided a source of precision 100 cycle per second signal which was put on a fourth channel of the oscillograph for use as a timing reference. The electrical firing impulse was fed into a fifth channel of the camera. The camera was operated at a paper speed of 48 inches per second. Fig. 5 is a block diagram of the 1956 instrumentation.

IV. RESULTS AND DISCUSSION

Profiles 1, 2, 5, 6, 9, 10, 11, and 12 were fired in 1955. In Figs. 1 and 2, the circle at the end of each profile designates the position of the listening ship during the firing of that particular profile.

In general, little evidence of a sediment velocity was apparent from these data. In most cases, two velocity lines were obtained for each profile, one associated with a high speed layer and a second, characteristics of an intermediate layer between the surface layer of unconsolidated sediments and the high speed layer. The reversed travel time graphs for these profiles are shown in Figs. 6, 8, 10, and 11. The equations defining the apparent velocity lines on these graphs are of the form $G = D/V + T_o$, where D is the distance between the shot and the receiver, expressed as water wave travel time, V is the velocity of sound in a particular layer with respect to the velocity of sound in sea water, and T_o is the intercept of the velocity line on the ordinate or ground wave travel time axis. The lines shown on these graphs are designated as G1, G2, and G3, where the G1 line refers to the sediment layer, the G2 line refers to the intermediate layer, and the G3 line refers to the third layer. The letters N, S, E, and W following the profile numbers on the graphs indicate the receiver position.

Calculations for the velocity of sound in sea water were made using Kuwahara's tables (U. S. Hydrographic Office, 1951) and correcting for temperature and salinity. The average temperature was determined from bathythermograph measurements taken over the lengths of the profiles. A salinity of 30 parts per thousand was assumed.

The 1956 data were obtained from reversed profiles 3, 4, 7, 8, 13, and 14, all 213.4 meters in length. Although the position of the listening ship varied between the 1955 and 1956 profiles, it was assumed that any sediment velocity information obtained would be representative of the area in question. The arrows alongside these profiles in Figs. 1 and 2 point toward the listening ship position during the firing of a particular profile.

Two velocity lines were obtained from the 1956 data, a low velocity line representing a sediment velocity, and a higher velocity line, associated with an intermediate subsurface layer. These lines are shown in Figs. 7, 9, and 12. No data pertaining to a high speed layer were obtained.

The calculations followed the method of Ewing, et al. (1939) and the results are summarized in Table 1. In general, the depths from the 1955 data are presumed to be accurate to 10 per cent, while the 1956 depths are thought to be accurate within 5 per cent. A 2 per cent error in velocity determinations is indicated.

Profiles 1 and 2. The area of profiles 1 and 2 lies west of, and parallel to, the northern end of Conanicut Island, with the greater part of the area having a flat bottom. The mean low water depth varies from 6.4 to 7.0 meters along the 3.2 km range, except near the south end where the range crosses a depression. Here the water is approximately 13 meters deep. Cores of the near surface sediments were composed of gravelly sand, muddy sand, sandy mud, and mud (Mulholland and Dietz, 1956).

Profiles 1 and 2 constitute a reversed refraction profile. Apparent third layer velocities of 5.55 km/sec for profile 1 and 5.53 km/sec for profile 2 were determined. A sediment velocity of 1.54 km/sec was established for profile 2. An apparent intermediate velocity of 4.48 km/sec resulted from profile 2, but insufficient points were present to establish a corresponding intermediate velocity for profile 1.

The results of a reflection survey made by the Gahagan Construction Corporation of New York in 1954 (private communication) in the Rome Point area, some 910 meters south of the south end of profile 1 indicate a gradual increase in the depth of the bedrock from about 9.1 meters at the shoreline to 46 meters at a point 2.7 km eastward from the mainland shore. The locations of these profiles are shown in Fig. 1.

In a survey made for the Woods Hole Oceanographic Institution in 1956, Berg (private communication) reported seismic profiles over an area some 29 km in length, extending from the mouth of the bay to the north end of the bay in the West Passage.

Using the information from these two sources, it was concluded that the sediment thickness at the south end of profiles 1 and 2 should be approximately 21 meters, giving a refracting horizon at 28 meters. Accordingly, the zero travel time intercept corresponding to this assumed depth was calculated and a velocity line was constructed between this calculated point and the maximum travel time intercept obtained from profile 2. The apparent velocity determined by this line was 4.48 km/sec. The line is shown dashed in Fig. 6.

Thus the depth of the upper refracting horizon was calculated to be 26 meters at the north end of the profile and was assumed to be

28 meters at the south end of the range. The depth of the lower refracting horizon was determined as 85 meters at the north end and 86 meters at the south end of the range. In summary, the seismic velocities were found to be 1.54 km/sec for the sediment layer, 4.48 km/sec for the intermediate layer, and 5.54 km/sec for the third layer. The intermediate layer velocity compares favorably with the bedrock velocity of 4.27 km/sec from the Gahagan data. The calculations for angle of dip indicate that the upper refracting horizon slopes slightly downward from north to the south, while the lower refracting horizon slopes upward in the same direction.

The increase in depth of the upper refracting horizon from north to south is substantiated by the results of seismic investigations carried out by the U. S. Army Corps of Engineers in 1956 (private communications) in two nearby areas. A survey from the Bonnet eastward to Conanicut Island indicates that the horizon between the unconsolidated sediments and the consolidated sediments reaches a depth of 82 meters at a distance of 610 meters from the mainland shore, and reaches a depth of about 92 meters at a distance of 790 meters from the west shore of Conanicut. This area lies some 6.4 km south of the Rome Point area. A gap in the data exists in mid channel, but presumably the horizon is deeper there. Another seismic section at the east end of the Jamestown Bridge site indicates a depth to the upper horizon of 37 meters at a distance of 610 meters from the Conanicut shore. The horizon depth at the bridge site is further established by borings made by Parsons, Brinkerhoff, Hall, and MacDonald, Engineers (private communication, 1954). Bedrock depths ranging from 32.9 meters at the center of the span to 14.9 meters near the east end of the span were reported.

No definite conclusions regarding the slopes of the horizons can be drawn from the limited information available. However, when compared with the horizon depths reported by the Gahagan Corporation (private communication, 1954) for the Rome Point area, as well as the depths determined in this investigation, an increase in the depth of the upper refracting horizon from north to south is suggested.

Additional information relative to the sediment thickness near the northern end of profiles 1 and 2 were reported by Nixon (1953) and Dietz, Mulholland, and Birch (1958), who found minimum sediment thicknesses of from 15 to 34 meters using jetted probes.

Profiles 3 and 4. These profiles cover a 213.4 meter range at the north end of profiles 1 and 2. Two velocity lines were obtained for each of these profiles. A sediment velocity of 1.54 km/sec was determined which agrees with that obtained from the shot records involved in profiles 1 and 2. Apparent velocities of 4.27 km/sec and 3.80 km/sec were obtained from the travel time graphs, and these resulted in a calculated velocity of 4.08 km/sec. This is assumed to be the velocity associated with the intermediate layer, which, as seen from profiles 1 and 2, shows a velocity of 4.48 km/sec. These figures are in agreement within 10 per cent. The thickness of the top sediment layer was found to be 20.7 meters at the north end of the profile and 16.8 meters at the south end. When considered with the depth of mean low water at these locations, it is seen that the depth of the refracting horizon is 27.1 meters at the north end and 23.2 meters at the south end. This compares favorably with the depth of 26 meters for the same horizon as determined from profiles 1 and 2 at a point some 300 meters to the north.

The intermediate velocity agrees reasonably well with the average velocity of 4.27 km/sec reported by the Gahagan Corporation (private communication, 1954). The sediment velocity of 1.54 km/sec lies within the range of 1.52 km/sec to 1.83 km/sec observed by the Corps of Engineers (private communication, 1956). Some evidence of similar velocities within this range was also observed by Berg (private communication, 1956).

Profiles 5 and 6. These reversed profiles were fired along a line slightly north of and parallel to the Quonset channel, and running generally east and west for a distance of 2.3 km. The mean low water depth along this range varies from 6.4 meters to 8.2 meters from the western end to the eastern end. The top 3.4 meters of sediment are very uniform. The western end is composed of sandy mud and the rest of the range is classified as mud (Mulholland and Dietz, 1956).

A sediment velocity of 1.55 km/sec was obtained from profile 5. Apparent velocities for the intermediate layer of 4.14 km/sec and 4.19 km/sec were derived from the graphs, as well as apparent third layer velocities of 5.47 km/sec and 5.79 km/sec. These resulted in calculated true velocities of 4.16 km/sec for the intermediate layer and 5.63 km/sec for the third layer. At the east end of the profile, the depth of the upper refracting horizon was calculated as 40 meters, and the lower refracting horizon as 180 meters. At the west end of the profile, the depths were calculated as 35 meters for the upper horizon and 130 meters for the lower horizon. The angles of dip also indicate that both horizons deepen from west to east.

A borehole by Fink (private communication, 1957) approximately 91 meters east of the west end of the range reached bedrock at a depth of 38.7 meters, in good agreement with the seismic data. Another boring near the east end of the range penetrated to a depth of 22.0 meters without reaching bedrock.

Profiles 7 and 8. These reversed profiles covered a 213.4 meter range near the west end of profiles 5 and 6. A sediment velocity of 1.56 km/sec was determined for this area. Apparent velocities of 3.61 km/sec and 4.94 km/sec were determined for the second layer. The resulting depth to the first consolidated horizon was 31.1 meters at the west end and 44.5 meters at the east end. These results pertain to an area very close to the 39 meter borehole mentioned above. The dip angle indicates increasing depth of the upper horizon from west to east.

The calculated velocity values for this profile were 1.56 km/sec for the sediment layer and 4.16 km/sec for the intermediate layer. These velocities agree with those found for profiles 5 and 6.

Profiles 9 and 10. These reversed profiles were fired in the Quonset channel and parallel to profiles 5, 6, 7 and 8. The mean low water depth varies from 9.8 meters to 11 meters from west to east. The eastern three-fifths of the 3.1 km range is underlain by a fine grained sediment of silt and sub-silt size. The sediments of the western end are mostly sandy mud (Mulholland and Dietz, 1956).

A sediment velocity of 1.77 km/sec is indicated by the travel time graphs. It is seen that this velocity is some 15 per cent higher than the velocities determined for the sediments in the nearby areas. One explanation for this is that the sediments in the channel have been dredged to a depth of some 4.6 meters below the level of the adjacent sediments. The sediment velocity of 1.77 km/sec, however, was determined from a minimum number of points. It was not considered advisable to anchor the shot line, used in the short range investigations, in the heavily traveled channel for the lengthy period required to fire a reversed profile. Therefore, supplementary information was not available.

It was necessary to use an approximate method in drawing the G2 line for profile 9, since most of the points fell along the G3 line. A line was drawn from the reverse point of the G2 line of profile 10 through the point on the G3 line closest to the origin. This line gave a minimum apparent velocity, while the zero time intercept gave a maximum apparent thickness to the second layer. Apparent velocities of 4.16 km/sec and 4.40 km/sec were determined for the intermediate layer. The calculated true velocity was 4.28 km/sec. The apparent velocities for the third layer were 5.54 km/sec and 5.69 km/sec, with a calculated true velocity of 5.61 km/sec. The associated depths were 24 meters at the west end of the range and 63 meters at the east end of the range for the upper horizon. The lower horizon was found to reach a depth of 170 meters at the west end and 130 meters at the east end. The dip angles indicate that the upper horizon slopes downward from west to east, signifying an increase in sediment depth, while the lower horizon slopes upward from west to east.

If the sediment velocity had been the same as the velocity of sound in water, 1.51 km/sec, instead of the reported value of 1.77 km/sec, an intermediate layer velocity of 4.30 km/sec would have resulted. The third layer velocity would then have been 5.63 km/sec. The depth to the upper refracting horizon would have been 21 meters at the west end and 55 meters at the east end. By the same token, the lower refracting horizon would have shown a depth of 170 meters at the west end and 120 meters at the east end. These figures represent decreases in the thickness of the sediment layer of from 10 to 15 per cent, while the decrease in the thickness of the intermediate layer is of the order of 6 per cent. An increase in velocity of both the intermediate layer and the third layer of less than 1 per cent would have resulted.

Profiles 11, 12, 13, and 14. These profiles, located in Greenwich Bay, and running generally east and west lie in shallow water 2.4 to 3.1 meters deep at mean low water.

The bottom sediments are uniformly fine, being composed of materials of silt size or smaller, with the first meter or so being extremely soft. The sediments at the ends of profiles 11 and 12 are sandy mud (Mulholland and Dietz, 1956). Profiles 13 and 14 are 213.4 meters in length and lie parallel to and approximately 730 meters east of the west end of profiles 11 and 12.

In some instances it was difficult to read the water wave travel times from profiles 11 and 12 because of the shallow water.

No definite sediment velocity could be established from the 1955 data. However, apparent intermediate velocities of 5.06 km/sec and 5.11 km/sec were seen. Apparent third layer velocities of 6.29 km/sec and 6.68 km/sec were also determined. A sediment velocity of 1.55 km/sec resulted from profiles 13 and 14, however, and this value was used as the sediment velocity for profiles 11 and 12. As a result, an intermediate velocity of 5.11 km/sec and a third layer velocity of 6.46 km/sec were calculated. The associated depths were 32 meters to the upper refracting horizon at the west end of profiles 11 and 12, and 43 meters at the east end. The depth of the lower refracting horizon was shown to be 250 meters at the west end and 340 meters at the east end.

The calculations for profiles 13 and 14 indicate an upper refracting horizon depth of 44.8 meters at the west end and a depth of 33.5 meters at the east end, 213.4 meters away. Apparent intermediate velocities of 5.01 km/sec and 3.79 km/sec were found, resulting in a calculated true velocity of 4.31 km/sec. The intermediate velocity of profiles 11 and 12 differs by approximately 15 per cent. A portion of this variation can be attributed to the scatter of points defining the 1956 G2 lines, in particular the G2 line of profile 14. On the other hand, since the water wave was so highly attenuated along the 1955 profiles, the possibility exists that the water arrivals observed on the records were actually not the beginning of the water wave, but represent a later portion of the wave. This could result in water wave travel times which were too long, and consequently the apparent velocities could be too high.

The dip angles from the 1955 data show an increase in depth of both horizons from west to east, while the data from profiles 13 and 14 indicate a decrease in depth of the upper horizon from west to east over the 213.4 meter range involved.

A jetted hole along profiles 11 and 12 reached a depth of 24.7 meters without striking bedrock, while a shallower hole slightly to the north penetrated to 15.2 meters, also without striking bedrock (Nixon, 1953).

A string of holes drilled by the Corps of Engineers (private communication, 1956) in a nearby area across the mouth of Greenwich Bay indicate bedrock at a depth of 33.8 meters in one location, while a nearby hole reached 35.4 meters with no evidence of bedrock.

V. SUMMARY

Three seismic velocities were in evidence over the areas covered in the investigation. Velocities ranging from 1.54 km/sec to 1.77 km/sec were determined for the unconsolidated sediment layer. For the three southern areas, velocities of from 4.08 km/sec to 4.48 km/sec were found for a second or intermediate layer. High speed velocities of from 5.54 km/sec to 5.63 km/sec were observed for a third layer.

The intermediate velocities are probably associated with the Rhode Island formation which underlies the sediments throughout much of Narragansett Bay (Shaler, et. al, 1899), (Quinn, 1952), and (Nichols, 1956), and these velocities seem to agree with those given by Birch (1942), Faust (1951), and Hughs (1952) for Pennsylvanian rocks of this nature. However, there are no specific seismic velocities available in the literature for the various types of rock in the Bay area.

Quinn (private communication, 1961) suggests that the high speed velocities might be characteristic of a firmly indurated and metamorphosed layer of the Rhode Island formation such as is found near the approach to the Jamestown Bridge. The possibility of a third layer of granite also exists, since the geologic maps (Quinn, 1952) and (Quinn and Oliver, in press) indicate a granitic bedrock beneath the surrounding land areas. Both rocks might be expected to exhibit similar seismic properties.

An intermediate layer velocity of 5.11 km/sec was determined for the area in Greenwich Bay. The layer is thicker here than in the southern areas. Presumably the Rhode Island formation exists beneath the sediment in this location also. A third layer velocity of 6.46 km/sec was found for this area, although the value is considered somewhat questionable, for the reasons previously discussed. Similarly, the intermediate velocity of 5.11 km/sec would be subject to the same considerations. The intermediate layer velocity of 4.31 km/sec obtained from profiles 13 and 14 agrees more closely with those of the other areas.

The sediment layer varies in thickness from about 29 meters to 42 meters in Greenwich Bay, while in the southern areas, the thickness ranges from approximately 14 meters to 52 meters.

The intermediate layer varies in thickness from about 210 meters to 290 meters in the Greenwich Bay location. In the lower bay, the thickness varies from approximately 58 meters to 150 meters.

Beneath the intermediate layer lies a third seismic layer which may be either granitic or a highly metamorphosed portion of the Rhode Island formation. In any event, it may be assumed that this layer is some form of crystalline complex.

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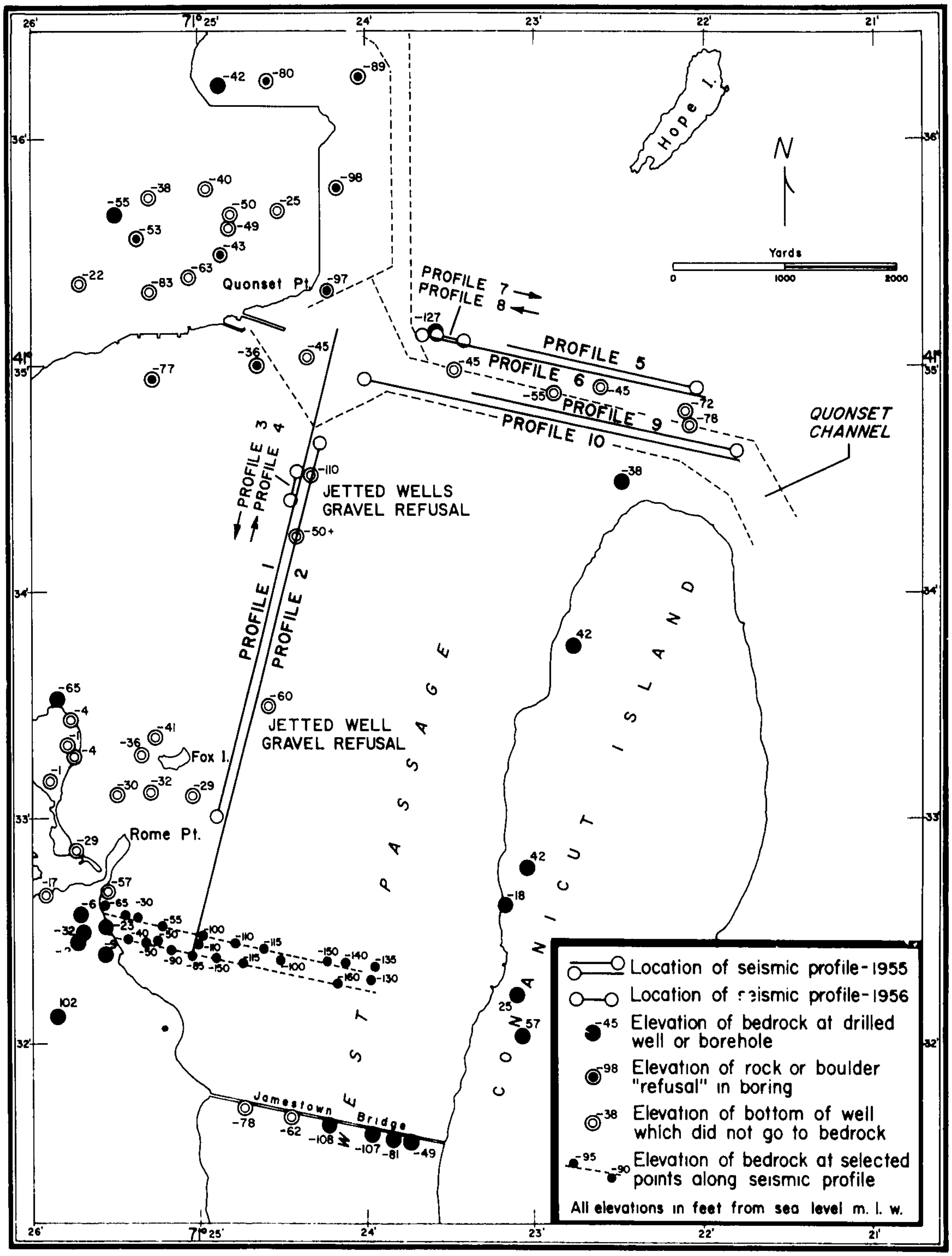

Fig. 1 Chart of Wickford Area, Showing Seismic
Profile Locations and Bedrock Information

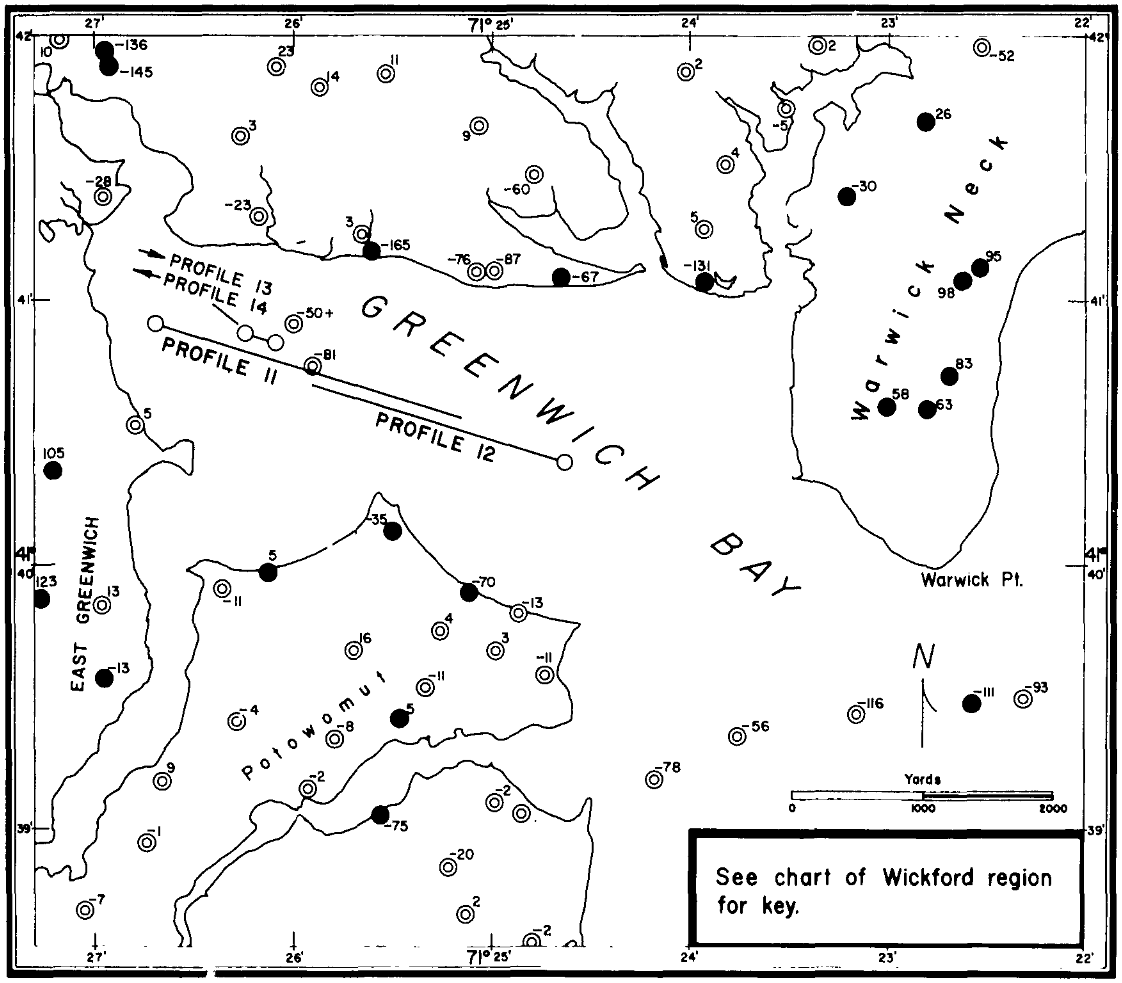

Fig. 2 Chart of Greenwich Bay Area, Showing Seismic Profile Locations and Bedrock Information

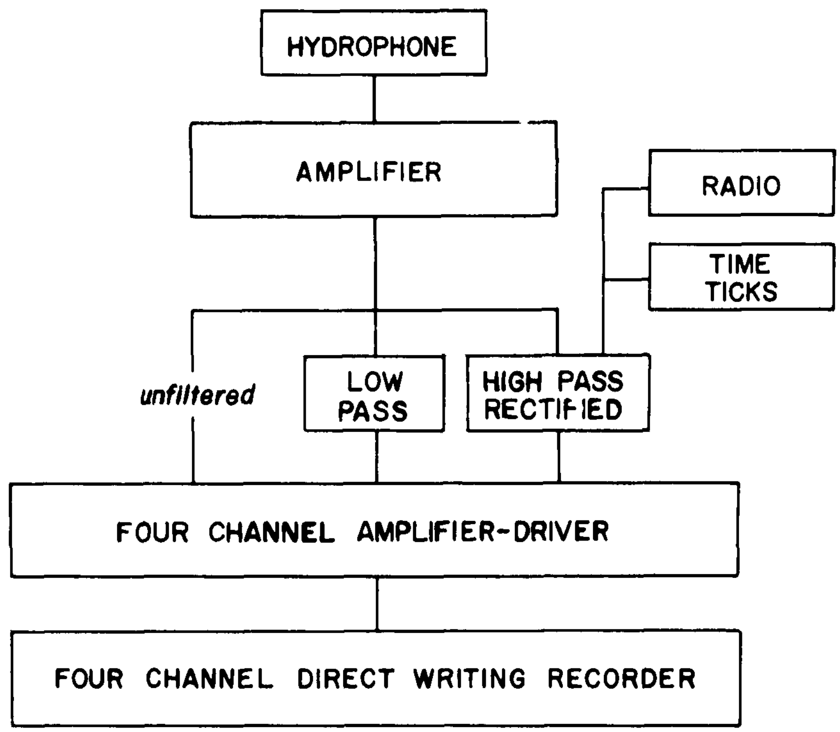

Fig. 3 Block Diagram of 1955 Instrumentation

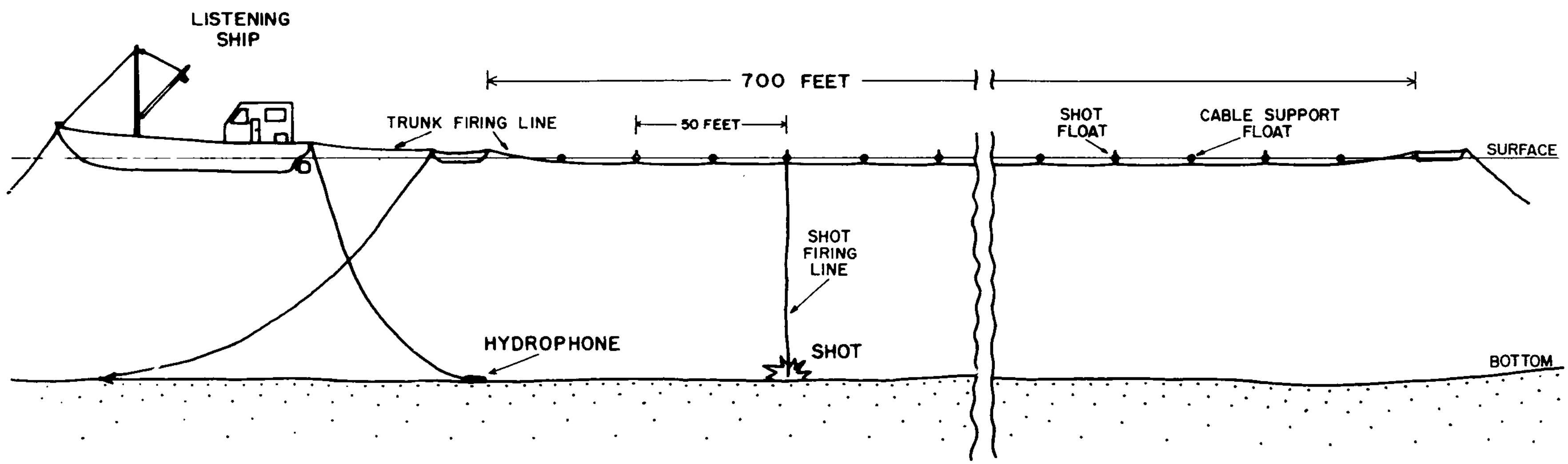

Fig. 4 Schematic Diagram of Shot Cable

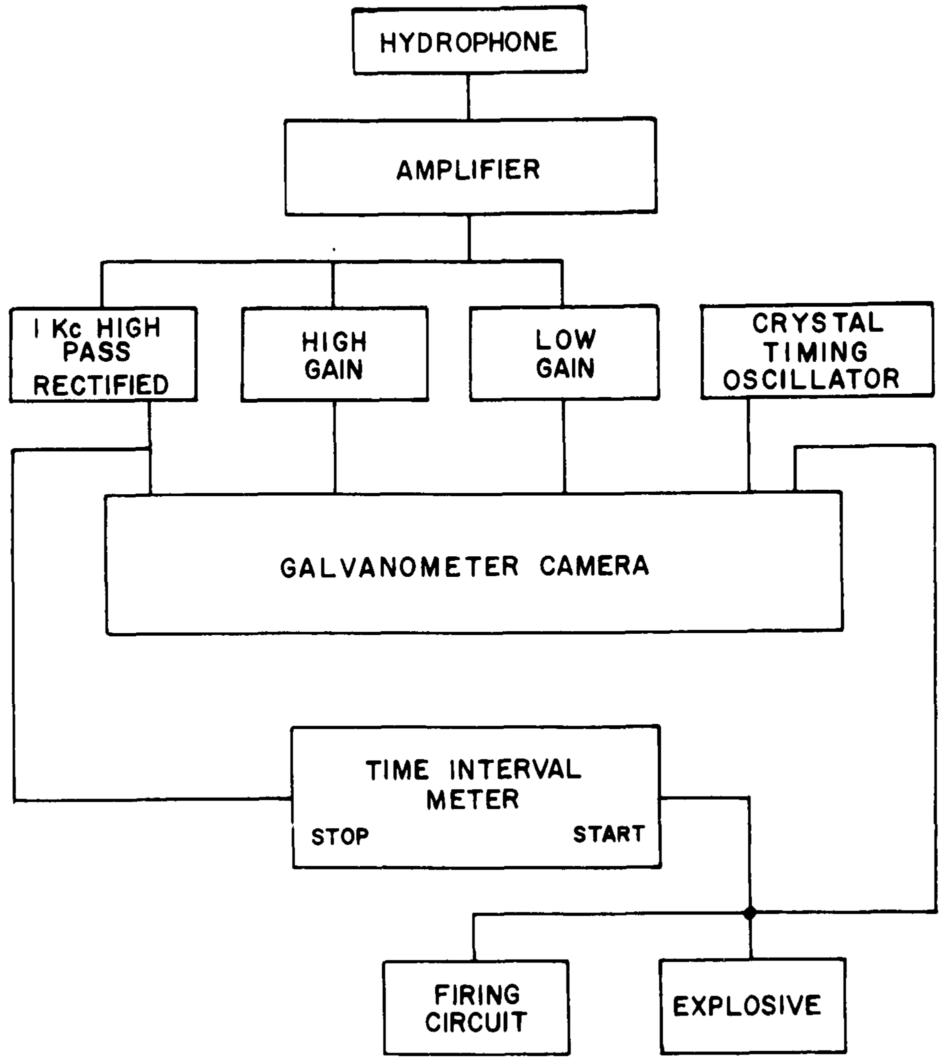

Fig. 5 Block Diagram of 1956 Instrumentation

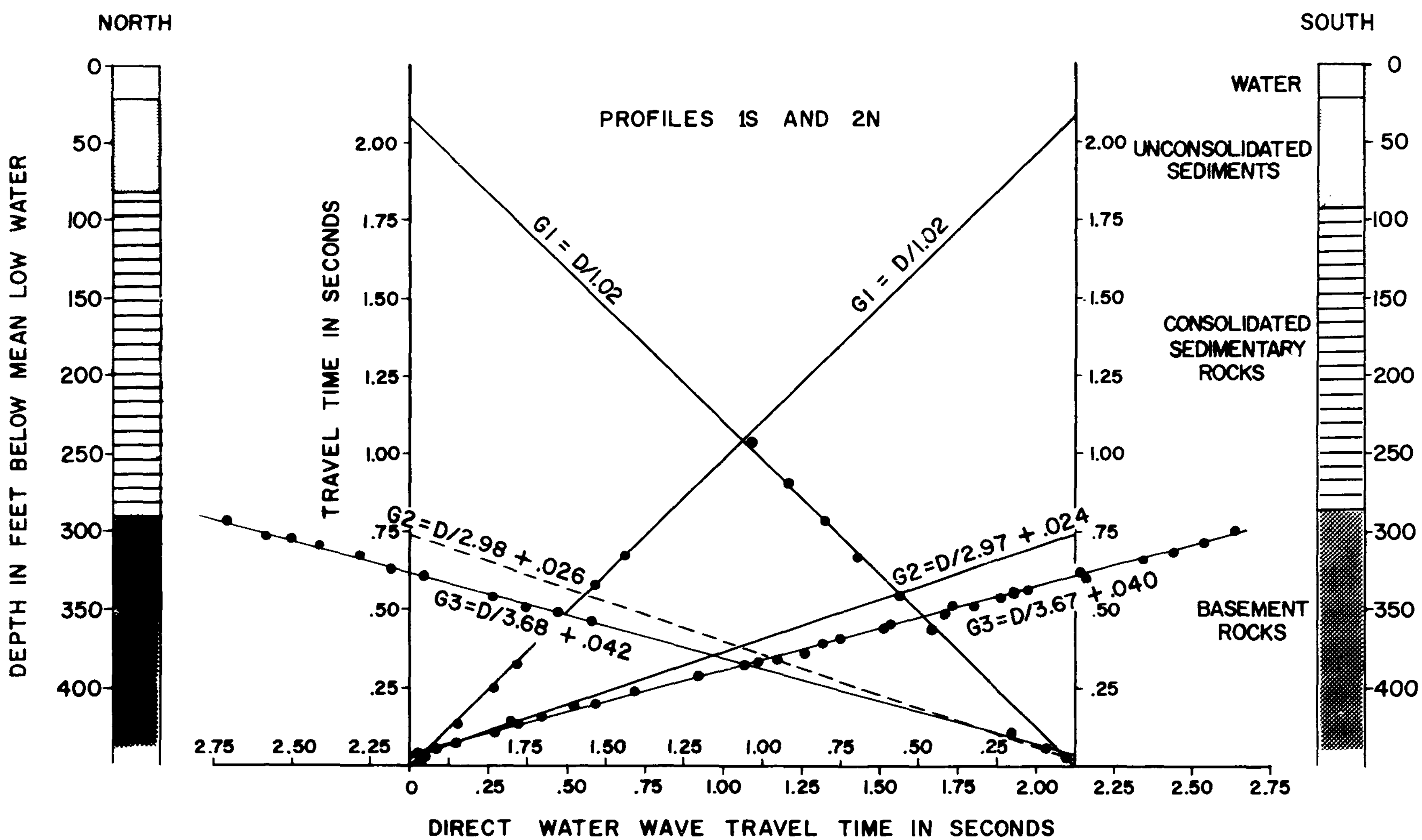

Fig. 6. Reversed Travel Time Graphs for Profiles 1 and 2.

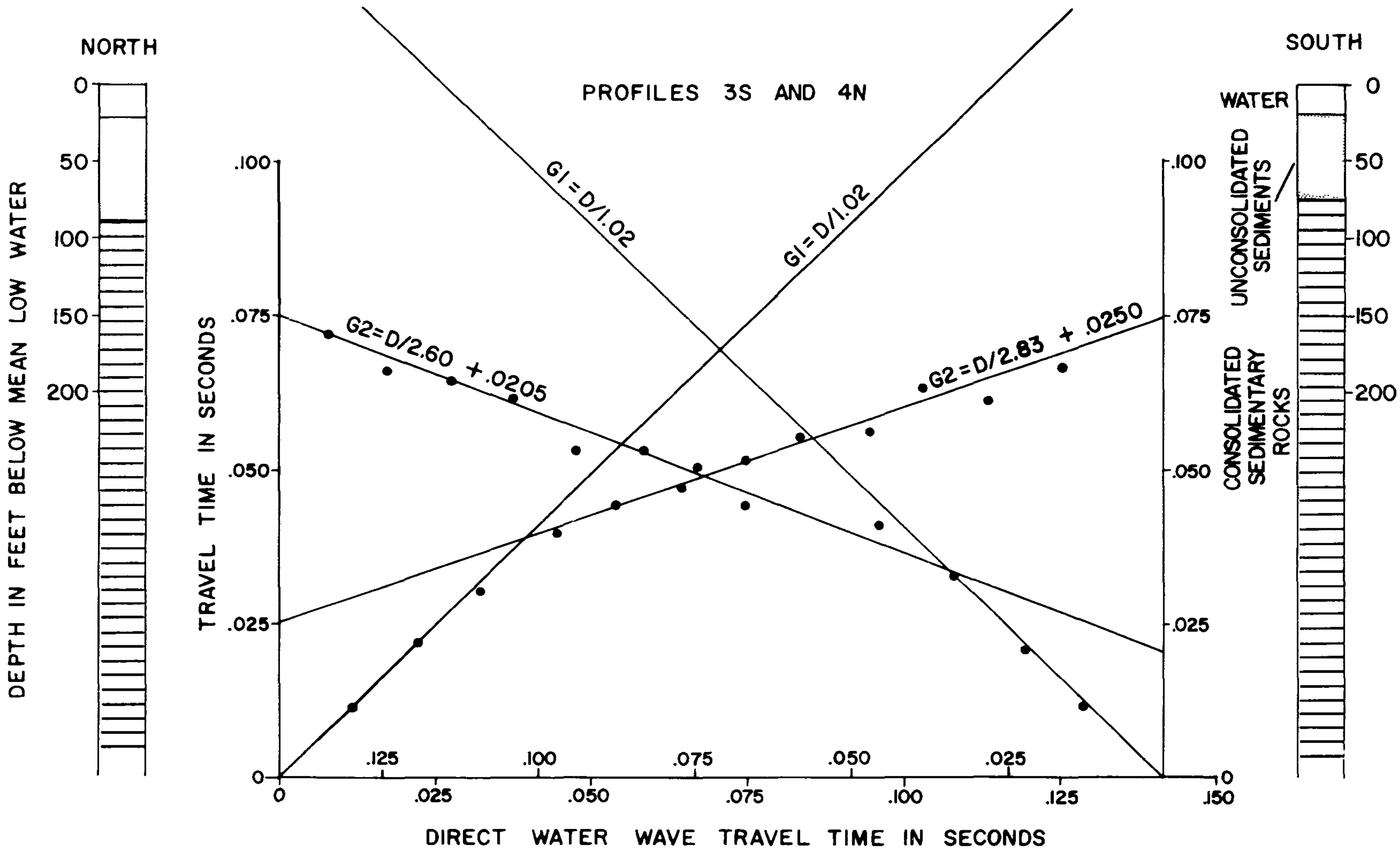

Fig. 7 Reversed Travel Time Graphs for Profiles 3 and 4

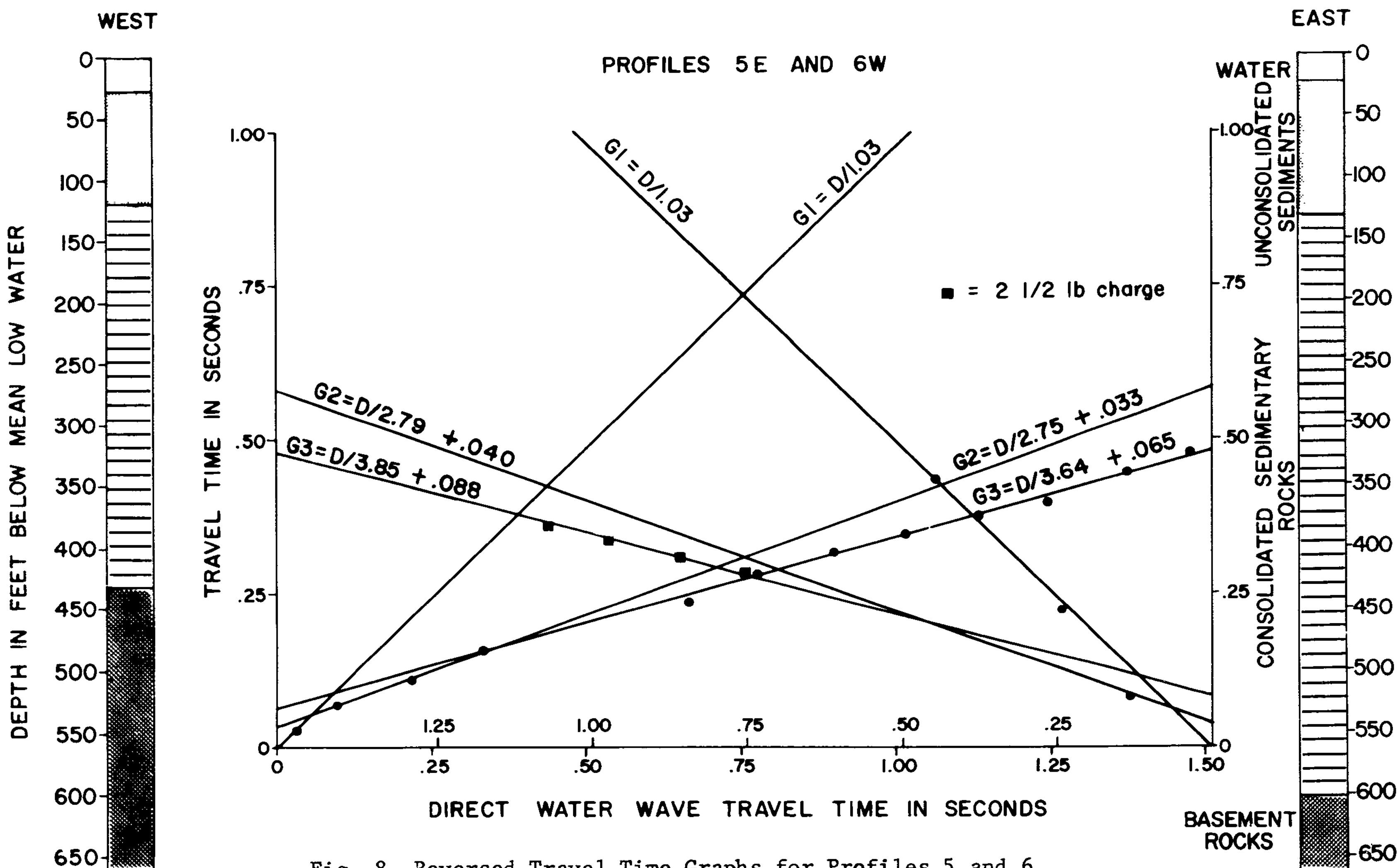

Fig. 8 Reversed Travel Time Graphs for Profiles 5 and 6

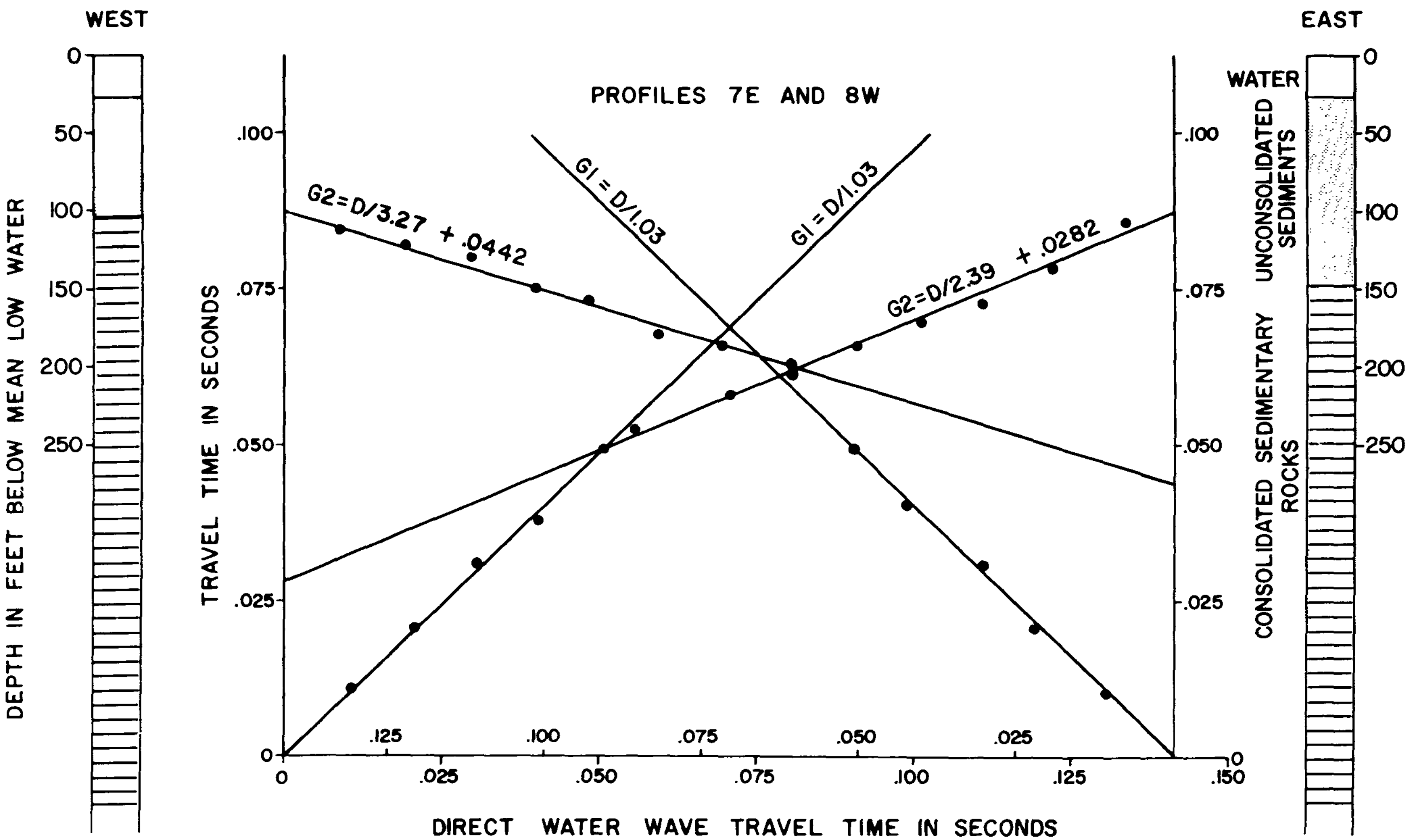

Fig. 9 Reversed Travel Time Graphs for Profiles 7 and 8

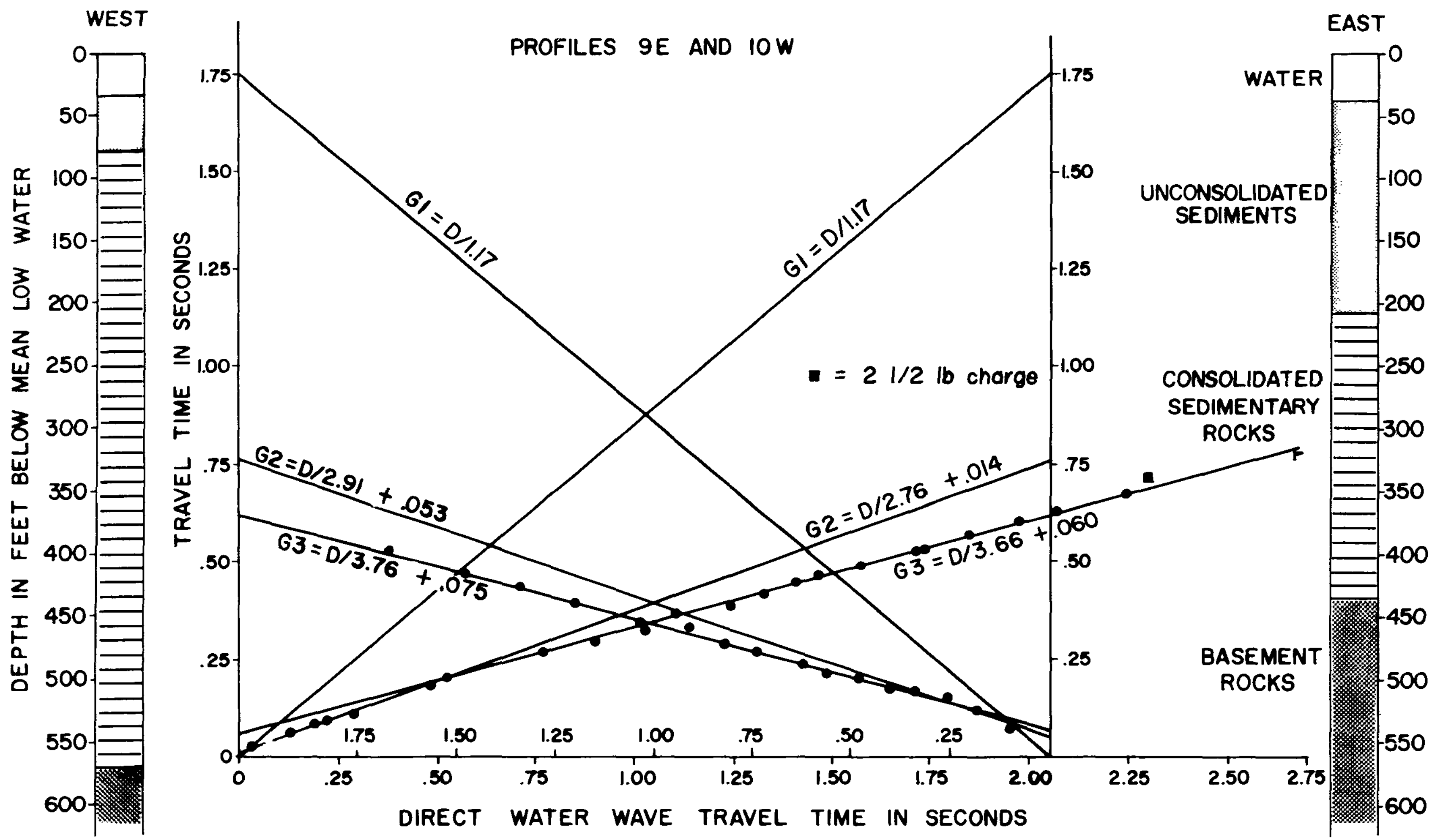

Fig. 10 Reversed Travel Time Graphs for Profiles 9 and 10

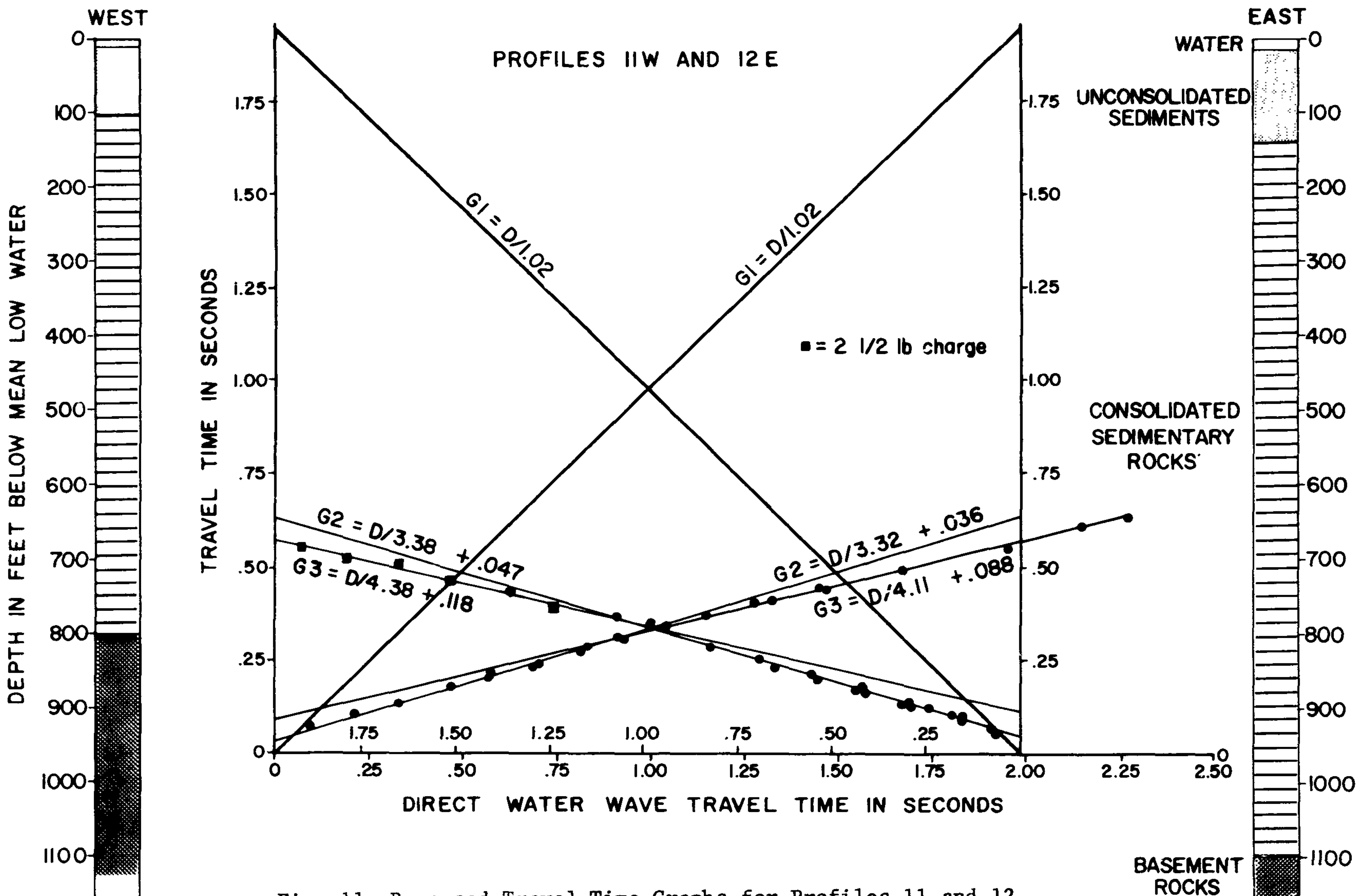

Fig. 11 Reversed Travel Time Graphs for Profiles 11 and 12

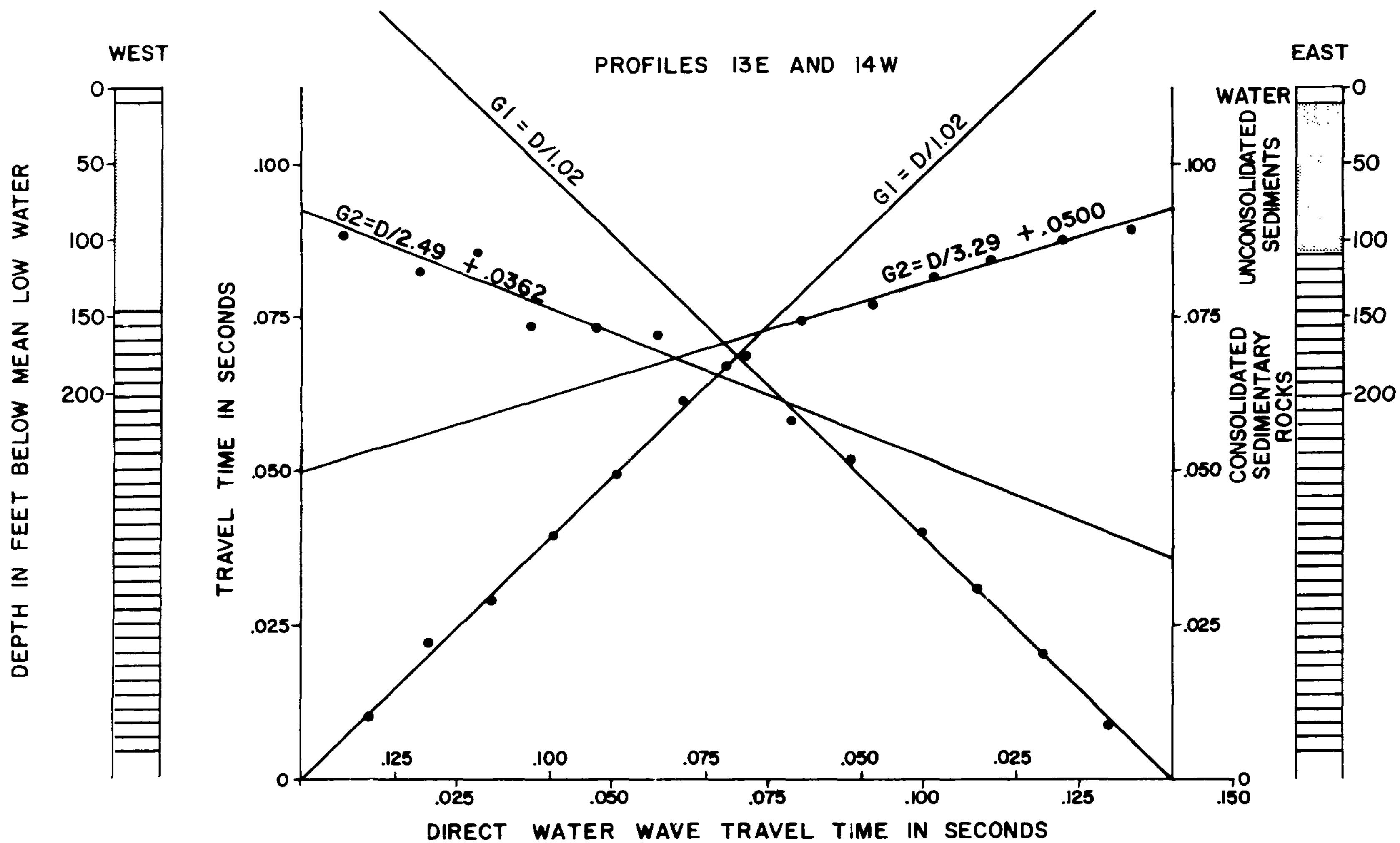

Fig. 12 Reversed Travel Time Graphs for Profiles 13 and 14

TABLE 1. Summary of Seismic Results

Profile	Depth to Upper Horizon (meters)	Depth to Lower Horizon (meters)	Surface Layer Velocity (km/sec)	Intermediate Layer Velocity (km/sec)	Third Layer Velocity (km/sec)
1 S	28	86	1.54	4.43	5.54
2 N	26	85			
3 S	23.2	-	1.54	4.08	-
4 N	27.1	-			-
5 E	40	180	1.55	4.16	5.63
6 W	35	130			
7 E	44.5	-	1.56	4.16	-
3 W	31.1	-			-
9 E	63	130	1.77	4.28	5.61
10 W	24	170			
11 W	32	250	1.55	5.11	6.46
12 E	43	340			
13 E	33.5	-	1.55	4.31	-
14 W	44.8	-			-

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